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Effects of Stratospheric Ozone Depletion on Marine Organisms

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16. ABSTRACT

As a result of stratospheric ozone depletion, UV-B radiation (290-320 nm) reaching aquatic environments is likely to increase over the next few decades. Available information suggests that UV-B radiation can have a variety of deleterious effects on marine and freshwater ecosystems. Most studies resulting in biological damage suggest that short-wavelength UV-B radiation below 300 nm is most effective. Thus, any long-term decrease in the ozone layer causing an increase in this radiation is likely to have adverse effects for biological systems. These effects can have a number of possible consequences for aquatic ecosystems. Among these effects are: 1) reduction in biomass production, resulting in a reduced food supply to humans; 2) change in species composition and a reduction of biodiversity; 3) decreased nitrogen assimilation by prokaryotic microorganisms, possibly leading to a drastic nitrogen deficiency for higher plant ecosystems, such as rice paddies, and 4) reduced sink capacity for atmospheric carbon dioxide, thereby augmenting the greenhouse effect.

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Effects of Stratospheric Ozone Depletion on Marine Organisms

Introduction

Inadvertent alterations of the Earth's atmosphere by human activities are now of regional and even global proportions. In the last decade scientists, policymakers, and the general public, have focused increasing concern on the consequences of a reduction of ozone in the upper atmosphere. The effects of this depletion will show no respect for national borders and will affect the entire Earth—a problem of truly global scale.

As a result of stratospheric ozone depletion, UV-B radiation (290-320 nm) reaching aquatic environments is likely to increase over the next few decades. Available information suggests that UV-B radiation can have a variety of deleterious effects on marine and freshwater ecosystems (for reviews *see* Worrest, 1982, 1986; USEPA, 1987). Even if individual nations or the international community find stratospheric ozone reduction at any level to be unacceptable and eliminate ozone-destroying chemicals, it could take decades-to-centuries to reverse the current trend. Therefore, anticipation of the consequences of the 'unavoidable' stratospheric ozone reduction, and the efforts to mitigate or adapt to such a decrease, are extremely important.

Primary Producers: Phytoplankton

Photosynthetic organisms on our planet are estimated to fix about 10^{14} kg of carbon annually. Planktonic organisms in the oceans fix more than half of this carbon (Houghton & Woodwell, 1989). The remainder is due to photosynthesis by all higher plants and freshwater plankton (*i.e.* crops, forests, grassland, tundra, lakes, etc.).

Because of their need for the Sun's energy, marine phytoplankton are restricted to the upper layers of their oceanic environment. Mutual shading, absorption, and light-scattering, prevent effective light penetration below the photic zone—below which phytoplankton cannot long survive. Even though partially attenuated, a significant amount of solar UV-B radiation penetrates into marine waters. This radiation presents a potential hazard for the planktonic organisms, because they do not possess the protective epidermal UV-absorbing layers that are characteristic of higher plants and animals. It is known that ambient or slightly increased doses of UV-B radiation can decrease phytoplanktonic primary production, although currently no quantitative assessment of any loss so-incurred in biomass production in aquatic systems is available. However, even a small loss will have a noticeably adverse effect.

In addition to the effects of UV-B radiation on photosynthesis by phytoplankton, UV-B radiation affects various adaptive capabilities (*e.g.* motility and orientation). Planktonic organisms are not equally distributed in the water column, but rather orient with respect to external factors such as light, gravity, chemical gradients, temperature, and the Earth's magnetic field (Nultsch & Häder, 1988). Experiments in laboratory and natural situations have shown that solar UV-B radiation drastically affects orientation, motility, and development, in these organisms—even after short exposure times (Häder, 1988; Häder & Griebenow, 1988; Häder & Häder, 1988*a*, 1988*b*, 1989). This reduces the chances for growth and survival of the populations concerned, which of course affects higher trophic levels as well. Experiments have also shown that UV-B radiation affects the general metabolism, photosynthetic energy production, and nitrogen fixation and assimilation, in many species (Worrest, 1982, 1986; Döhler, 1985; Döhler *et al.*, 1986, 1987; USEPA, 1987).

Nitrogen assimilation is one of the key processes for growth, because it determines the rate of protein synthesis. Prokaryotic organisms, such as Cyanobacteria, are capable of utilizing atmospheric nitrogen dissolved in water—a metabolic mechanism of which higher plants cannot avail themselves. Thus, Cyanobacteria play an important role in providing nitrogen for higher plants (*e.g.* in tropical rice production). The annual nitrogen assimilation by the Cyanobacteria alone has been assumed to amount to 3.5×10^{10} kg globally, which exceeds the 3.0×10^{10} kg of artificial nitrogen fertilizer produced annually. Some of these organisms are extremely sensitive to current levels of UV-B exposure (Häder *et al.*, 1986). A significant decrease in the nitrogen fixation by prokaryotic microorganisms will inevitably affect growth and productivity of higher plants. The amount of artificial nitrogen fertilizer necessary to compensate for a substantial loss will stress the capabilities of lesser-developed countries.

Consumers: Marine Animals

Various experiments have demonstrated that UV-B radiation causes direct damage to juvenile fish, shrimp larvae, crab larvae, and other small animals that are essential to the aquatic food-web. These damaging effects include decreased reproductive capacity, growth, survival, and other reduced functions (Worrest, 1986; Siebeck & Böhm, 1987). Although not as important as light, temperature, or nutrient levels, evidence indicates that ambient solar UV-B radiation is currently a substantially limiting ecological factor. Even small increases of UV-B exposure could result in significant ecosystem changes (Damkaer, 1982).

Effects on Zooplankton:—Marine invertebrates differ greatly in their sensitivity to UV-B radiation (Dey *et al.*, 1988). Larval shrimps exhibit a mortality threshold that is close to the reported UV-B dose near the surface of the sea in spring, but the radiation dose of the longer days of summer at mid-latitudes exceeds this threshold. Larval crabs have a slightly higher threshold sensitivity to UV-B radiation (Damkaer & Dey, 1983). These mortality thresholds for UV-B radiation are higher than UV-B levels for existing or anticipated column-ozone concentrations, but they are well below the possible levels around midsummer, even without ozone depletion. Given a 16% ozone decrease over temperate pelagic waters, UV-B radiation levels at a depth of one metre would reach a lethal (50% mortality) cumulative radiation dose in fewer than five summer days for about half the zooplankton species examined. Perhaps even more importantly, the threshold levels of UV-B exposure would occur earlier in the year than habitually, when these species are normally found near the surface (Damkaer *et al.*, 1981; Dey *et al.*, 1988).

Effects on Fisheries:—UV-B stress is most likely to affect fisheries in two ways: through eggs and/or larvae, and through effects on the food-chain upon which the juvenile fish depend. The bulk of the world's marine harvest of fish, shellfish, and crustaceans, consists largely of species of which the eggs and larvae are habitually at or near the sea's surface, where they would be exposed to increasing levels of UV-B radiation following stratospheric ozone decrease (Hardy, 1982). Enhanced solar UV-B radiation directly

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reduces the growth and survival of larval fish (Hunter *et al.*, 1982). Because virtually all anchovy (various species of isospondylous fishes of the family Engraulidae) larvae occur within the upper water column and are exposed to solar radiation, an ozone reduction could lead to large increases in larval mortality.

As mentioned, evidence indicates that increased UV-B irradiance could also result in fishery losses indirectly through effects on the planktonic food-web. Based on one assessment, a 5% decrease in primary production (estimated for a 16% ozone depletion) would yield reductions in fish yield of approximately 6 to 9%. A 7% reduction in fish yield, if it occurred on a global basis, would then represent a loss of about 6×10^{10} kg of fish per year.

Indirect effects on fisheries may also occur in the form of altered patterns of predation, competition, diversity, and trophic dynamics, if species resistant to UV-B radiation were to replace sensitive species. Scientists have not, as yet, been able to predict reliably the combined effects of direct (larval mortality) and indirect (food-web) losses on fisheries yield, nor have they been able to assess the adaptive strategies or genetic selections that could minimize population or ecosystem effects, or those on biodiversity.

Change in Species Composition and Biodiversity

In marine plant communities, a major change in species composition—in addition to a global decrease in net production—might result from enhanced UV-B exposure (USEPA, 1987). A change in community composition at the base of food-webs may produce instabilities within ecosystems affecting organisms higher in the food-web (Kelly, 1986). The generation-time of marine phytoplankton is in the range of hours to days, whereas the potential increase to ambient levels of solar UV-B irradiance resulting from stratospheric ozone depletion would occur in the range of decades. The question remains as to whether the gene-pool within species is variable enough to enable species to become adapted during this relatively gradual change in exposure to UV-B radiation (with respect to the generation-time of the target organisms).

Atmospheric CO_2 Concentration and Global Climate Change

Another important consequence of a potential decrease in marine phytoplanktonic growth is a reduction in the important 'sink' for the carbon dioxide that is produced globally. Oceans take up a major proportion of the carbon dioxide that is released annually. A 10% decrease in the carbon dioxide uptake by the oceans would leave about the same amount of carbon dioxide in the atmosphere as is currently produced by fossil-fuel burning. This effect would have long-term consequences for the global climate, and would enhance the predicted sea-level rise.

In addition, if UV-B radiation inhibits dimethyl sulphide (DMS) production by marine phytoplankton, this could result in a reduction in the formation of atmospheric cloud-condensation nuclei, decreased cloudiness, and concomitantly increased incident solar radiation (including UV-B radiation)—in other words, a positive destructive feedback loop. However, an alternative prediction argues that a substantial warming of the atmosphere would increase the evaporation from the oceans and thus cause a more massive cloud formation. At this time, the variables controlling DMS production are not well understood, while the potential consequences of these conflicting processes contribute to the uncertainties associated with the global warming issue.

Risks of UV-B Damage

If increased solar UV-B radiation impairs the productivity of marine organisms, the effects may be dramatic both for the commonly very intricate marine ecosystems and for the human population, which is affected by this system. More than 30% of the world's animal protein for human consumption comes from the sea, and in many countries this percentage is significantly larger. Any reduction of this productivity will undoubtedly affect the global food supply. In addition, a decrease in the size of the phytoplankton populations will result in a higher CO_2 concentration in the atmosphere, which will augment the CO_2 increase caused by fossil fuel burning. This consequence of stratospheric ozone depletion is not yet accounted for by the current climate change/greenhouse effect models.

In summary, it has been found that UV-B radiation affects marine organisms in the following ways: 1) altering their adaptive strategies (*e.g.* motility and orientation); 2) impairing important physiological functions, such as photosynthesis and enzymatic reactions; and 3) causing death during developmental stages (*e.g.* the young of finned fishes, shrimp larvae, and crab larvae).

Most pertinent studies of biological damage to marine organisms suggest that short-wavelength UV-B radiation below 300 nm is the most effective. Any long-term decrease in the ozone layer, by causing an increase in this radiation reaching the sea, is likely to have adverse effects on marine biological systems. These effects can have a number of possible consequences for aquatic ecosystems. Among these effects are 1) reduction in biomass production, resulting in a reduced food-supply to humans; 2) change in species composition and a reduction of biodiversity; 3) decreased nitrogen assimilation by prokaryotic microorganisms, possibly leading to a drastic nitrogen deficiency for ecosystems dominated by vascular plants, such as rice paddies; and 4) reduced sink capacity for atmospheric carbon dioxide, thereby augmenting the 'greenhouse effect'.

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Physico-chemical and Biological Properties of Effluent-affected Soil at Varanasi, India

Introduction

In recent years, the quality of the environment in parts of India has been deteriorating rapidly owing to increasing industrialization and widespread urbanization. Thus some soils have become polluted by industrial effluents (Tripathi, 1975), though the soil microflora play an important role in releasing mineral nutrients through decomposition and hence improving the productivity of the soil (Lasebikan, 1974; Singh & Tripathi, 1978; Sweeney & Graetz, 1988). However, little information is available about the effects of industrial effluent on the soil mycoflora in India (Rai & Tiwari, 1975; Tiwari, 1975; El-Nennah *et al.*, 1982; Whelan & Barrow, 1984; Whelan, 1988). In view of this prevailing paucity of information, the present investigation has been undertaken around the Hari fertilizer factory near Varanasi, India.

Description of Sites, Climate, Soil, and Vegetation

The study-sites are situated around the Hari fertilizer factory (83° 1′ E long. and 25° 18′ N lat.), about 15 km north-east of Banaras Hindu University. The sites for investigation were selected as being practically antitheses, the polluted-soil site being quite near to the discharge-point of the effluents, whereas the unpolluted site was well away from the discharge-point.

The climate of the region is typically monsoonic, as described by Misra (1969), and this is reflected in the vegetation. The year has three distinct seasons, namely rainy (from July to October), with warm (30–35°C) and humid (70–80% relative humidity) weather and about 80% of the total annual precipitation, winter (from November to February) with dry and relatively cold weather (20–28°C diurnal temperature), and hot summer (37–44°C temperature) from March to June, with strong and dry wind (30–40% relative humidity). The soils are of clayey to sandy loam texture and light-yellow to dark-brown in colour. The soil reaction is alkaline (pH 7.0–8.4), being rich in exchangeable calcium.

The natural vegetation of the Upper Gangetic Plain was originally a tropical deciduous forest (Misra, 1969), but currently the land is mainly under cultivation with two crops (Rabi and Kharif) harvested in the year. Small areas of grassland are quite common.

Materials and Methods

Samples of the liquid effluent were collected in stoppered bottles from the discharge-point between 8 and 10 AM, and various physico-chemical parameters such as temperature (at the time of sampling), pH, carbonate ions, bicarbonate ions, sodium ions, potassium ions, calcium ions, magnesium ions, nitrate-N, ammonium-N, total nitrogen, suspended solids, dissolved solids, total solids, and chloride ions, were analysed following the methods given in APHA (1985). Residual sodium carbonate (RSC) was calculated according to the method of Eaton (1950).

Soil samples were taken randomly with a graduated iron core sampler measuring 762 × 106 × 325 mm, surface litter and weeds having been removed carefully from the plot before sampling. Ten samples of soil were collected fortnightly from each site throughout the winter season (4

months) in 1987, giving a total of 180 samples. Samples were analysed in the laboratory for (a) porosity and water-holding capacity (Misra, 1968), (b) pH, exchangeable sodium, carbonate, and total nitrogen (Hesse, 1970), and (c) numbers and kinds of soil Fungi.

Isolation and Identification of Fungi

The soil samples were homogenized thoroughly in separate sterilized flasks, aseptic techniques being used. Ten grammes of soil from each sample were suspended in sterile distilled water, shaking on a mechanical shaker (90 throws min^{-1}) and serially diluted to 10^{-2}, 10^{-3}, and 10^{-4}. A 1 ml aliquot from each dilution was inoculated on each of six Petri-dishes. About 15 ml of Martin's (1950) cooled agar medium was then poured into each Petri-dish and well mixed with the soil suspension. The plates were incubated at 25 ± 1°C for six days. The numbers of colonies of Fungi on the plates were then counted and identified with the help of available literature (Gilman, 1957; Barnett & Hunter, 1972), slow-growing and non-sporulating forms having been transferred to fresh nutrient agar prior to identification.

The number of Fungi per g of dry soil was calculated (Warcup, 1955), and after the fungal species had been finally identified, their frequency and overall abundance were recorded by the methods of Saksena (1955). The frequency and abundance of each fungal species that had been identified was calculated by averaging the number of Fungi isolated from each soil dilution and applying the following formulae:

$$\text{Frequency (\%)} = \frac{\text{Number of occurrence of a species}}{\text{Total number of plates}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of colonies of a species}}{\text{Number of plates on which a species occurred}}$$

Results

The physico-chemical properties of the polluting effluent (average of 180 samples) are given in Table I. The data revealed far higher concentrations of sodium (306.9 mg/l), carbonate (107.9 mg/l), and bicarbonate (617.8 mg/l), in the effluent than in well-water, where concentration of

TABLE I

Physico-chemical Characteristics of Effluent Compared with Well Water (average of 180 samples).

Parameter	*Effluent*	*Well Water*
Temperature (°C)	51.7 ± 3.9	24.0 ± 2.4
pH	9.61± 1.24	7.40± 0.62
Carbonate (mg/l)	107.9 ± 6.7	5.6 ± 2.0
Bicarbonate (mg/l)	617.8 ±10.7	48.7 ± 2.5
Chloride (mg/l)	148.7 ±10.8	17.5 ± 2.3
Residual sodium carbonate (mg/l)	3.9 ± 1.0	—
Ammonium–N (mg/l)	81.4 ± 4.7	0.06± 0.01
Nitrate–N (mg/l)	15.5 ± 2.7	0.34± 0.03
Total Nitrogen (mg/l)	141.7 ±16.7	13.7 ± 1.4
Sodium (mg/l)	306.9 ±15.4	8.4 ± 2.2
Calcium (mg/l)	124.5 ±16.7	84.7 ± 1.9
Magnesium (mg/l)	26.7 ± 6.8	26.6 ± 2.1
Potassium (mg/l)	26.7 ± 2.9	2.8 ± 0.4

± Mean S.D. value.

TABLE II

Physico-chemical Characteristics of Polluted and Unpolluted Soil at 0–25 cm Depths (average of 180 samples).

Parameter	Polluted Soil	Unpolluted Soil
Porosity (%)	42.6 ± 1.7	56.7 ± 1.8
Water-holding capacity (%)	32.4 ± 0.92	56.7 ± 0.6
Soil temperature (°C)	31.4 ± 1.6	29.5 ± 2.4
pH	8.91± 0.82	6.45± 0.32
Exchangeable Na (me/100 g)	10.7 ± 1.7	0.7 ± 0.04
Carbonate (% dry-weight)	3.06± 0.5	0.80± 0.3
Total Nitrogen (%)	0.19± 0.06	0.03± 0.004
Potassium (me/100 g)	3.9 ± 0.6	3.0 ± 0.4
Calcium (me/100 g)	9.8 ± 0.9	6.7 ± 0.7
Magnesium (me/100 g)	3.2 ± 0.8	2.6 ± 0.4
Cation exchange capacity (me/100 g)	13.75± 2.6	17.58± 2.9

± Mean S.D. value.

sodium (8.4 mg/l), carbonate (5.6 mg/l), and bicarbonate (48.7 mg/l), were recorded. There were also higher concentrations of sodium (10.7 mg/100 g), carbonate (3.06% dry-weight), and total nitrogen (0.19% dry-weight), in the polluted soil (Table II). The pH value of polluted soil was also higher (8.91) than that of the unpolluted soil (6.45). Porosity and water-holding capacity of the polluted soil were markedly lower than in the unpolluted soil. Soil temperature was the same at both sites.

The investigation of the soil fungal flora (Table III) indicated that polluted soil supported fewer species (11) of microfungi than the unpolluted soil (16). Quantitatively, the number of Fungi isolated was also lower in the polluted habitat (1.4×10^4 g^{-1} oven-dry soil) than in the unpolluted

TABLE III

Frequency Per Cent and Abundance of Fungi in Polluted and Unpolluted Soils.

Fungal species	*Polluted soil*		*Unpolluted soil*	
	Frequency Class	*Abundance Class*	*Frequency Class*	*Abundance Class*
Rhizopus nigricans	11	1	2	1
R. oryzae	0	0	1	1
Mortierella stylospora	5	2	0	0
Ceratostomella adiposa	2	1	0	0
Trichoderma harzianum	3	1	0	0
Aspergillus fumigatus	0	0	2	1
A. sydowi	0	0	1	1
A. terreus	0	0	5	1
A. flavus	2	1	4	1
A. humicala	5	1	2	1
A. niger	0	0	3	1
A. sulphureus	2	1	0	0
Penicillium javanicum	0	0	1	1
Trichophyton sp.	0	0	1	1
Acrophialophora fusispora	0	0	5	1
Cladosporium herbarum	5	1	1	1
C. epiphyllum	4	1	0	0
Curvularia lunata	0	0	2	1
C. tuberculata	1	1	1	1
Fusarium poae	4	2	2	1
Rhizoctonia solani	0	0	1	1
Total Number of species	11	16	16	16
Total Number of Fungi (g^{-1} oven-dry soil)	1.4×10^4		2.2×10^4	

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